IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Appln. of:	Paul Fredrick Luther Weindorf	
Appln. No.:	10/840,039	Examiner: Leonid Shapiro
Filed:	May 5, 2004	Art Unit: 2629
For:	LUMINENCE DEGRADATION REDUCTION THERMAL FEEDBACK METHOD	Confirmation No. 7760
Attorney Docket No:	10541-1998	

DECLARATION OF PAUL FREDRICK LUTHER WEINDORF UNDER 37 C.F.R. §1.131

Commissioner for Patents
U.S. Patent and Trademark Office
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

I, Paul Fredrick Luther Weindorf, hereby declare that:

1. I am the inventor of the subject matter claimed in the above-identified application.

2. I conceived the claimed subject matter in the United States prior to September 17, 2003 (the §102(e) date of U.S. Pat. Pub. 2005/0068270), as evidenced by the date in the "Records of Invention" section of the Invention Disclosure form, the written description in the "Attachments" section of the Invention Disclosure form, and the drawings attached to the Invention Disclosure form. The Invention Disclosure form being attached to this affidavit as Exhibit A.

3. That said invention was diligently worked on from a date prior to September 17, 2003 until the filing date of the instant application.

4. That all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statement may jeopardize the validity of the above-identified application, and any patent issuing thereon or any patent to which this declaration is direction.

Dated: April 3, 2009

Paul Fredrick Luther Weindorf

Paul Fredrick Luther Weindorf

EXHIBIT A

OLID

Visteon

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Related Links: View Invention Disclosure | Assign/Evaluate Disclosure | View Invention Ranking | Email Disclosure

Online Invention Disclosure: View Invention Disclosure

Inv. Discl. Docket No:	V203-0268
Creation Date:	5/1/03
Approval to submit was given by:	PWEINDOR: 01-MAY-03

Section 1: INVENTION DESCRIPTION

Title of Invention:	OLED LUMINANCE DEGRADATION REDUCTION THERMAL FEEDBACK METHOD
Patent Evaluation Committee:	$VTM
CPSC Code:	15.00.00
Originating Country Code:	US
Related Disclosure(s):	199-1910

Section 2: PROBLEM & SOLUTION

Description or Comments:	OLED displays are not typically used in automotive applications due to severe luminance reduction as a result of high temperature exposure. This patent outlines a thermal feedback method to reduce the OLED drive as a function of temperature thereby minimizing OLED luminance degradation. The attachment mathmatically outlines the problem and presents the improvements that can be expected utilizing the patent method.
Attachment:	See Section:9 ATTACHMENTS

Section 3: PRIOR ART

Description or Comments:	OLED companies are pursuing higher temperature materials. However, since the luminance degradation always increases exponentially with temperature, the thermal feedback method will afford operational improvements even with the new materials.
Attachment:	See Section:9 ATTACHMENTS

Section 4: DETAILED DESCRIPTION

Section 4: DETAILED DESCRIPTION

Description or Comments: The attachment describes the detailed method of reducing the luminance as a function of OLED temperature to decrease the amount of luminance degradation.

Attachment: See Section:9 ATTACHMENTS

Section 5: DATES

Record(s) of Completion: 6/28/02 recorded in Visteon notebook 236 pages 73-93.

Date of Completion: 6/28/02

First Production Use: [Model and Date] : Unknown

Section 6: MISCELLANEOUS ITEMS

Is it a Government Contract?: No

If yes, Government Contract Number:

Identify a government agreement, partnership, consortium, or other company involved with conception or first building of the invention:

If disclosed to non-Company personnel, identify recipient and date:

Identify potential licensing oppurtunities within and, as appropriate, outside the auto industry. If possible, name potential companies that should be contacted:

Section 7: ATTACHMENTS

File Name Click on File Name to view and print it.	**Description**
34210Problem_And_Solution.doc	Your original attachment file : AutomotiveOLEDLifePredictionMethod2.doc was renamed.

Section 8: INVENTORSHIP

CDS or Other Id:	PWEINDOR
Last Name:	Weindorf
First Name:	Paul
Middle Name:	Fredrick Luther
Employment Category:	[redacted]
Employment Status:	[redacted]
Job Title:	Technical Specialist
Email:	[redacted]
Office Phone Number:	[redacted]
Fax:	[redacted]
Social Security or Company ID Number:	[This field is blocked out intentionally.]
Citizenship:	US
Home Address Line 1:	[redacted]
Home Address Line 2:	[redacted]
City, State & Zip Code:	
Country Code:	US
Employee of:	Visteon Corporation
Department:	[redacted]
Organization Code:	
Business Unit:	
Payroll Location Code:	[redacted]
Office Address:	Visteon Technical Center - AP, DTC62B01
Maildrop:	vtc 6200
Supervisor's CDS Id:	[redacted]
Manager's CDS Id:	[redacted]

Automotive OLED Life Prediction Method

Background: Currently there is a lot of industry buzz surrounding the use of OLED displays and their purported benefits. However, in contrast to light valve technologies that do not suffer from differential aging, emissive technologies must be carefully analyzed and used to ensure that the lifetime expectations are met. In general light valve technologies such as liquid crystal, interferometric modulator, LCOS, micro-mirror, and electrophoretic displays depend on a general light source that decays over time. However these light valve displays do not suffer appreciably from differential aging whereby portions of the display used more frequently emit or reflect a lower luminance than portions used less frequently. On the other hand, emissive technologies such as CRT, VF, FED, Plasma, EL and OLED displays all suffer from the differential aging phenomena and thus requiring screen saver functions if the same data is displayed for long periods of time. For CRT phosphors, this was studied extensively by Bell Labs and it was determined that phosphors decay as a function of total electron accumulation on the phosphor and not as a function of the total electron energy. This of course led to the use of higher anode voltages because more life could be obtained from the phosphor at the same luminance levels. This same phenomena also led to higher voltages in VF and FED displays. Although OLEDs have many benefits, its Achilles heel is aging which is accelerated substantially at elevated temperatures commonly associated with automotive environments. By developing an analysis method to predict and understand the amount of aging, methods may be developed which can successfully use this display technology. Some of the items to consider are:

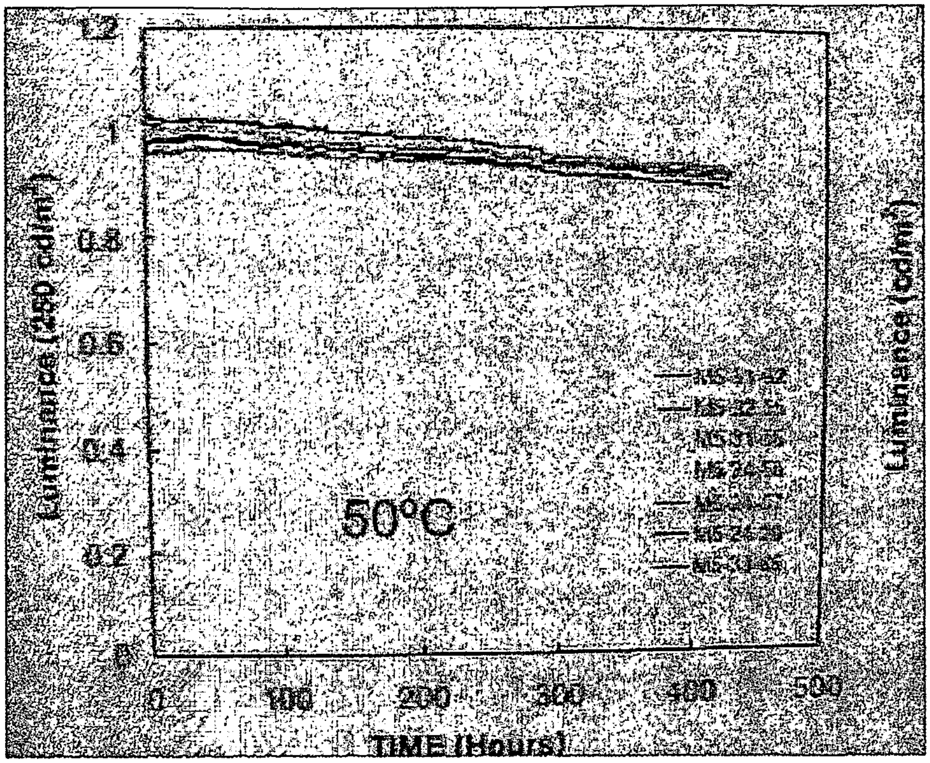
- Running pixilated display in the reverse mode during day (i.e. information is not lit, background is lit) and running in normal mode at night. This will actually be a more readable display for both applications and help reduce the differential aging.
- Use automatic light sensing control hardware and algorithm to control the display luminance during daytime operation. This will provide significant reduction in expended life.
- Measure the temperature of the display and limit the display luminance as a function of temperature.
- Utilize some type of special dithering program where in the data is dithered in a Gaussian manner.

Analysis:

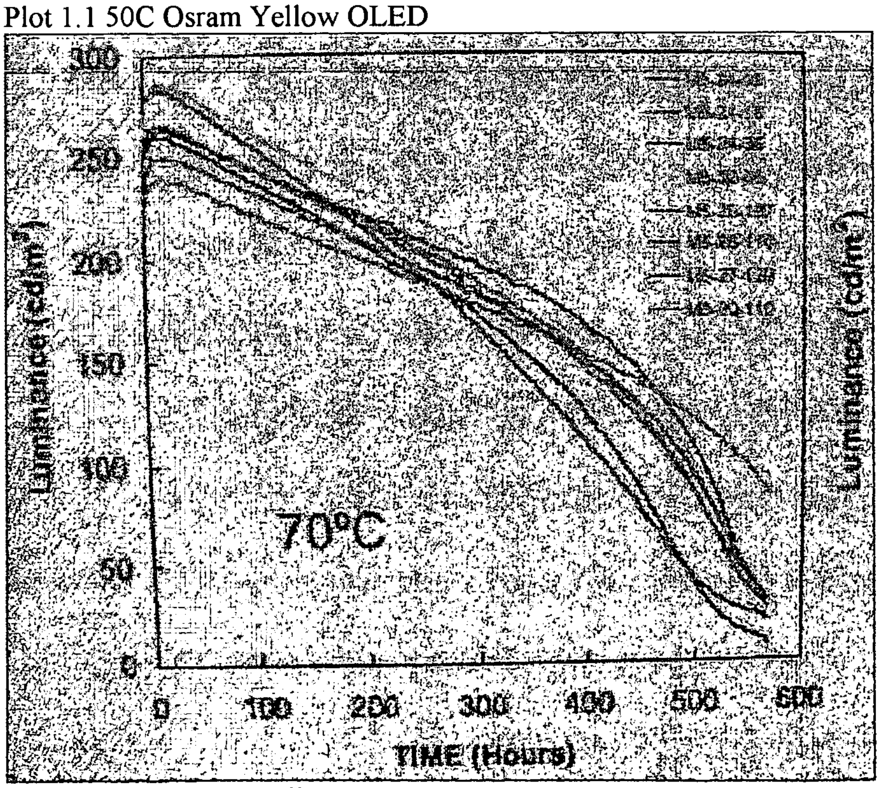
I could not find much published data on OLED luminance degradation as a function of temperature and luminance, so this analysis uses some data provided to me by OSRAM and TDK. As more data is obtained, it will be incorporated.

1.0 Luminance Decay Time Function

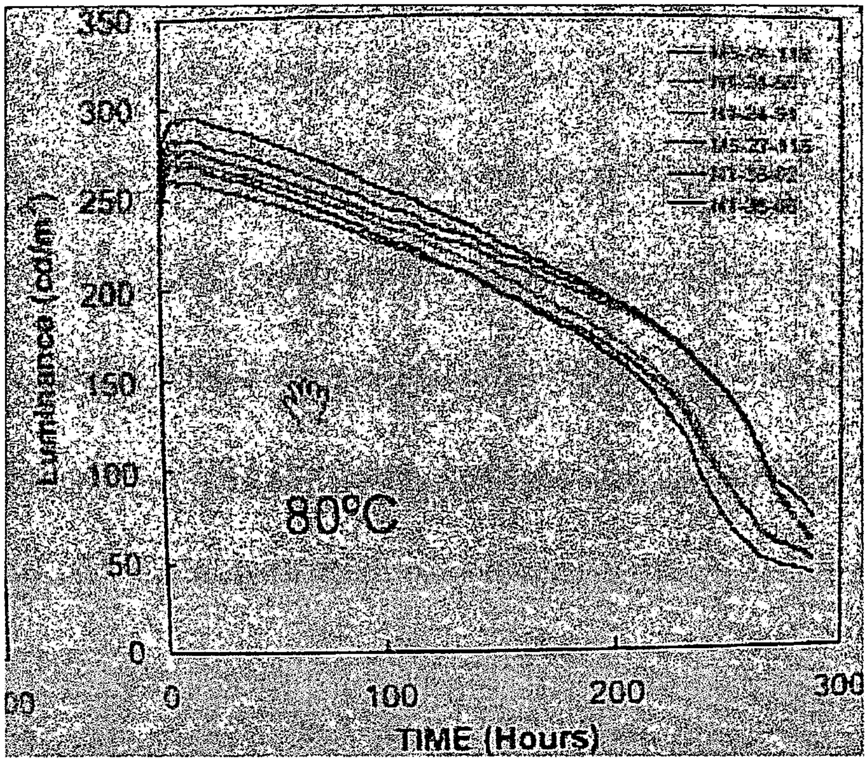
As a result of life time testing performed by OSRAM on their yellow material, plots 1.1,1.2 and 1.3 were obtained at various temperatures.



Plot 1.1 50C Osram Yellow OLED



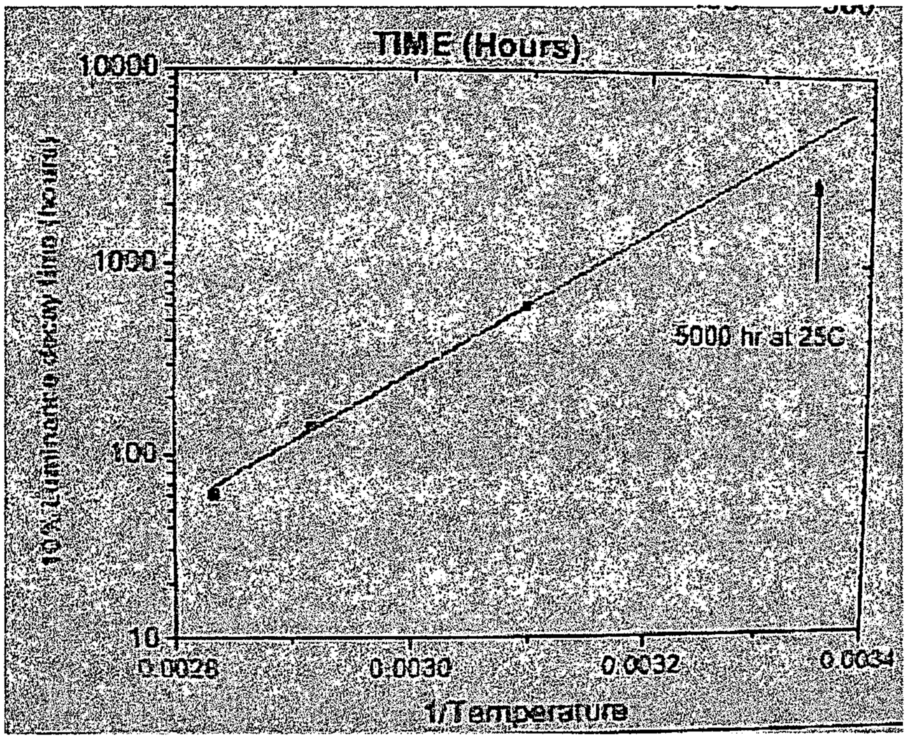
Plot 1.2 70C Osram Yellow OLED



Plot 1.3 80C Osram Yellow OLED

What is important to note from these plots is that the luminance decay is approximately linear until about ½ luminance degradation. This is important because it means that the luminance consumption is additive in nature. This greatly simplifies the mathematics required since it implies that the consumption at various temperatures can be added to find out the total luminance degradation.

The next step is to obtain a formula for the consumption rate at each temperature. Accordingly, OSRAM has plotted the 10% luminance degradation curve (Plot 1.4) and has shown it is approximately linear on a log scale as a function of 1/T, where T is the temperature in Kelvin.



Plot 1.4 10% Luminance Decay as a Function of $1/T_{KELVIN}$

By noting the logarithmic relationship, one can determine that the equation for the function to be of the form as shown in Equation 1.1. What is important to note is that the decay time decreases more than exponentially as the temperature increases.

$$Hours_{-10\%} = K_1 e^{K_2(1/T)} \qquad \text{(Eq 1.1)}$$

Since the decay rate at each temperature is approximately linear to ½ luminance, any decay point down to −50% could be used. Solving for constants K_1 and K_2 in Equation 1.1 is shown in Equations 1.2 through 1.11).

$$600 = K_1 e^{K_2(0.0031)} \quad \text{for T=50°C+273°C} \qquad \text{(Eq 1.2)}$$

$$60 = K_1 e^{K_2(0.00283)} \quad \text{for T=80°C+273°C} \qquad \text{(Eq 1.3)}$$

$$\frac{600}{e^{K_2(0.0031)}} = \frac{60}{e^{K_2(0.00283)}} \qquad \text{(Eq 1.4)}$$

$$\frac{600}{60} = e^{K_2(0.0031) - K_2(0.00283)} \qquad \text{(Eq 1.5)}$$

$$\frac{600}{60} = e^{K_2(0.0031 - 0.00283)} \qquad \text{(Eq 1.6)}$$

$$\ln(10) = K_2(2.7x10^{-4}) \quad \text{(Eq 1.7)}$$

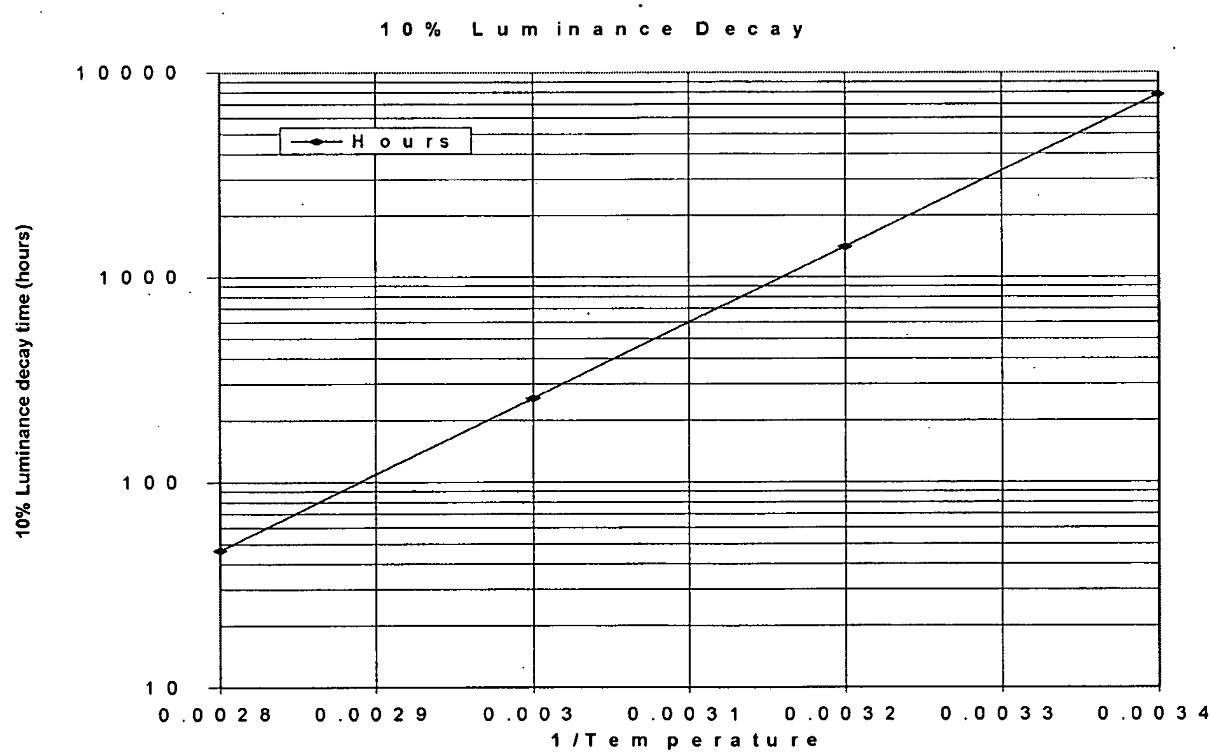
$$K_2 = 8.53K \quad \text{(Eq 1.8)}$$

$$600 = K_1 e^{(8.53K)(0.0031)} \quad \text{(Eq 1.9)}$$

$$K_1 = 1.968x10^{-9} \quad \text{(Eq 1.10)}$$

$$H_{-10\%} = 1.968x10^{-9} e^{8.53K(1/T)} \quad \text{(Eq 1.11)}$$

A plot of Equation 1.11 is shown in Plot 1.5 and is in close agreement with Plot 1.4.



Plot 1.5 OSRAM Yellow Luminance Decay

Equation 1.11 can now be used in section 2.0 to determine a general method to determine OLED luminance degradation for various automotive user profiles.

2.0 Life Model Equation

As discussed earlier, since the consumption rate is linear at each temperature, integration techniques can be utilized since Equation 1.11 provides the consumption rate as a function of temperature.

$$ConsumptionRate = CR = \frac{Nits}{Hour} \qquad \text{(Eq 2.1)}$$

Note that the meaning of Equation 2.1 is that the Nits used up is the Nits at room temperature at normal drive. Next the consumption rate formula can be determined by noting that the definition of Equation 1.11 is where the luminance falls by 10%.

$$CR = \frac{L_i(0.1)}{1.968x10^{-9} e^{8.53K(1/T)}} \qquad \text{(Eq 2.2)}$$

where
L_i+ Initial Luminance
T is the temperature in Kelvin

Next it is assumed that temperature changes in the automotive environment change in an exponential manner. For instance when a user enters the automobile after it has been cooking in the sun, the temperature will generally decrease to a comfortable room ambient assuming the air conditioning is functioning. The temperature function can therefore be modeled per Equation 2.3.

$$T = T_2 + \Delta T e^{-t/\tau} \qquad \text{(Eq 2.3)}$$

where
T_1 is the initial temperature
T_2 is the final temperature
$\Delta T = T_1 - T_2$
τ = time constant

Substituting Equation 2.3 into Equation 2.2 yields Equation 2.4.

$$CR = \frac{L_i(0.1)}{1.968x10^{-9} e^{8.53K(\frac{1}{T_2 + \Delta T e^{-t/\tau}})}} \qquad \text{(Eq 2.4)}$$

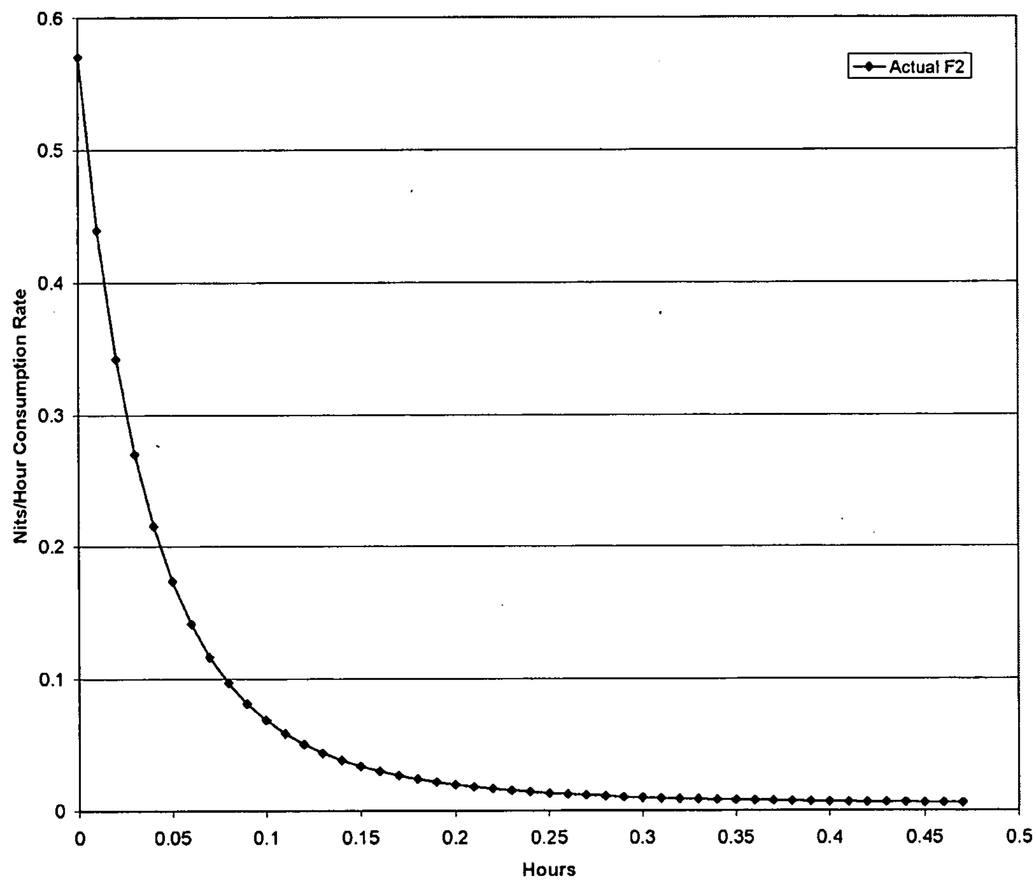
Next the consumption rate can be integrated over time to yield the total luminance consumption for a hot start as outlined in Equation 2.5.

$$Lu\min ance\_Decrease = LD = \int_0^t \frac{L_i(0.1)}{1.968x10^{-9} e^{8.53K\left(\frac{1}{T_2 + \Delta T e^{-t/\tau}}\right)}} dt \qquad \text{(Eq 2.5)}$$

As an example, choose T_2=85°C and T_1=25°C. Also substitute 250 Nits for L_i.

$$LD = \int_0^t \frac{25}{1.968x10^{-9} e^{8.53K\left(\frac{1}{298+60e^{-t/0.15}}\right)}} dt \qquad \text{(Eq 2.6)}$$

Note that a time constant of τ=20minutes=0.15hours was chosen. Equation 2.6 is a difficult integral to perform. When the function to be integrated is plotted per Plot 2.1, a function which appears to be approximately exponential in nature is revealed.



Plot 2.1 Consumption Rate Function for an 85°C Hot Start

Since an exponential function is much easier to deal with, an approach that tries to curve fit an exponential function will be utilized. The first thing to do is to determine the initial and final values per Equations 2.7 and 2.8.

At t=0

$$CR = \frac{250(0.1)}{1.968x10^{-9} e^{8.53K\left(\frac{1}{298+60}\right)}} = 0.570 \frac{Nits}{Hour} \qquad \text{(Eq 2.7)}$$

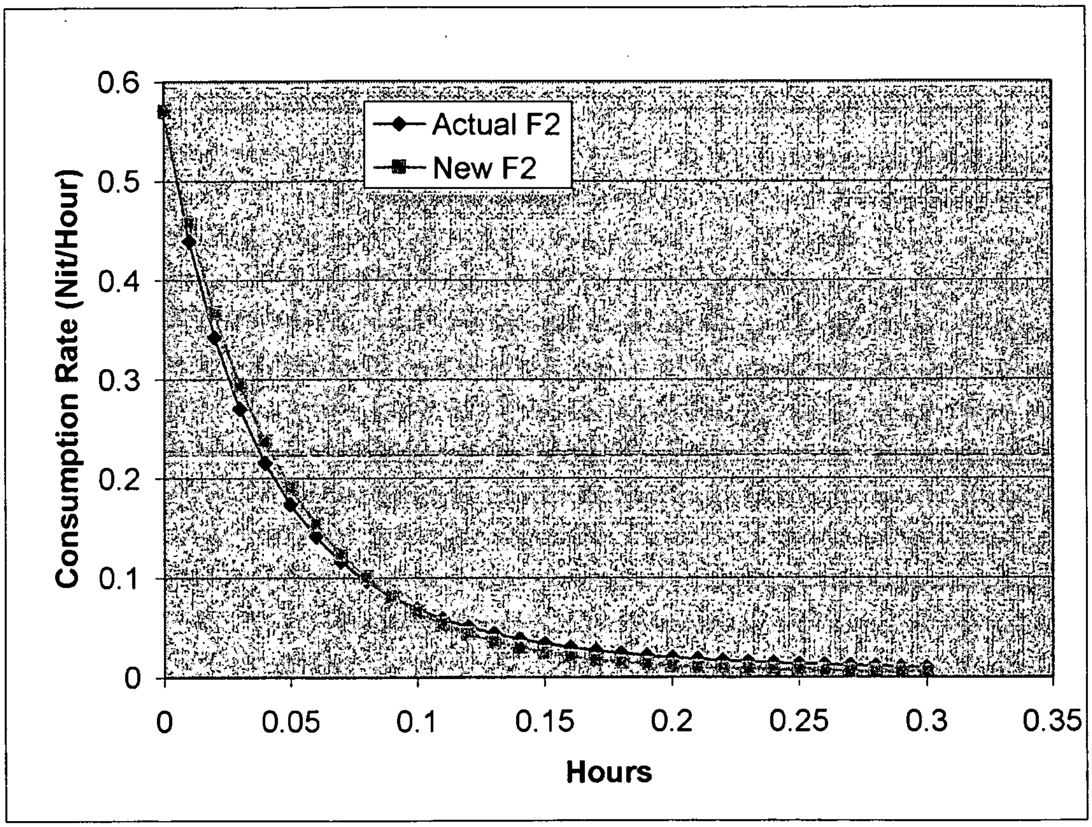
At t=∞

$$CR = \frac{250(0.1)}{1.968x10^{-9} e^{8.53K\left(\frac{1}{298}\right)}} = 0.0047 \frac{Nits}{Hour} \qquad \text{(Eq 2.8)}$$

Note that the difference between the results for Equation 2.7 and 2.8 is 0.5653. Therefore one can now develop the curve fit function per Equation 2.8.

$$CR = 0.0047 + 0.5653 e^{-t/0.045} \qquad \text{(Eq 2.9)}$$

Plot 2.2 shows Equation 2.9 against the original function per Equation 2.4.



Plot 2.2 Original CR versus New Curve Fit CR for 80°C OSRAM Yellow

Using the simpler exponential Equation 2.9 in the integral of Equation 2.6 yields Equation 2.10.

$$LD = \int_0^t 0.0047 + 0.5653e^{-t/0.045}dt = 0.0047t + \left.\frac{0.5653e^{-t/0.045}}{\left(-1/0.045\right)}\right|_0^t = 0.0047t + \left[\frac{0.5653e^{-t/0.045}}{\left(-1/0.045\right)} - \frac{0.5653}{\left(-1/0.045\right)}\right]$$

$$LD = 0.0047t + (0.5653)(0.045)\left[1 - e^{-t/0.045}\right] = 0.0047t + 0.02544\left[1 - e^{-t/0.045}\right] \qquad \text{(Eq 2.10)}$$

From observation of Equation 2.10, when t>>0.045hours (2.7minutes), 0.02544 Nits of luminance decrease will occur. In other words, each hot start uses 25.44mNits up and the nominal room temperature operational luminance will be this amount lower. The .0047t term shows that for each hour of operation at room temperature, the luminance will decrease by 4.7mNits.

To see what happens as the temperature is decreased, let's see what happens when the hot start temperature is +50°C. Modifying Equation 2.4 for 50°C yields Equation 2.11.

$$CR = \frac{250(0.1)}{1.968x10^{-9}e^{8.53K\left(\frac{1}{298+25e^{-t/.15}}\right)}} \qquad \text{(Eq 2.11)}$$

At t=0,

$$CR = \frac{25}{1.968x10^{-9}e^{8.53K\left(\frac{1}{298+25}\right)}} = 0.043129\frac{Nits}{Hour} \qquad \text{(Eq 2.12)}$$

At t=∞, the CR=0.0047 and is the same as the last case. Therefore, the +50°C case equation is per Equation 2.13.

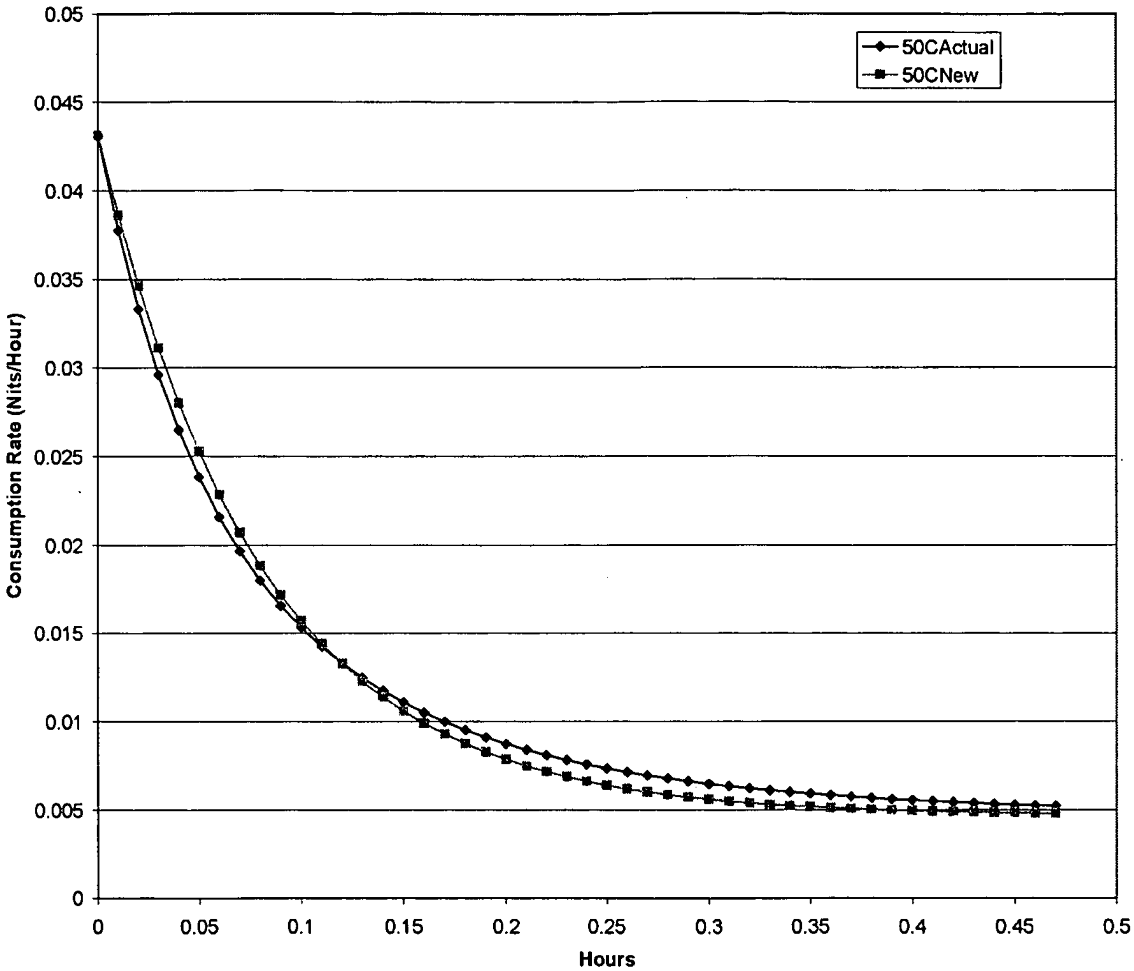
$$CR = 0.0047 + 0.038429e^{-t/\tau} \qquad \text{(Eq 2.13)}$$

However in evaluating the time constant, Plot 2.3 shows that a time constant of 0.08 is a better choice for +50°C than the time constant of 0.045 used for the +85°C case. Integrating Equation 2.13 yields the results of Equation 2.14.

$$LD = \int_0^t 0.0047 + 0.038429e^{-t/0.08}dt = 0.0047t + \left.\frac{0.038429e^{-t/0.08}}{\left(-1/0.08\right)}\right|_0^t = 0.0047t + \left[\frac{0.038429e^{-t/0.08}}{\left(-1/0.08\right)} - \frac{0.038429}{\left(-1/0.08\right)}\right]$$

$$LD = 0.0047t + (0.038429)(0.08)\left[1 - e^{-t/0.08}\right] = 0.0047t + 0.00307\left[1 - e^{-t/0.08}\right] \qquad \text{(Eq 2.14)}$$

From the results of Equation 2.14, it can be observed that the extra luminance consumption of 0.00307 Nits due to the 50°C hot start is much less than the 0.02544 Nits consumed by an 85°C hot start. Once again note that the consumption rate of 0.0047 Nits/Hour is for 25°C operation.



Plot 2.3 Original CR versus New Curve Fit CR with 0.08 Time Constant

3.0 Luminance Drive Life Function

To account for various OLED drive levels the equations developed so far must be modified. Per Homer Antoniadis at OSRAM,

"As you possibly know the lifetime of our OLED devices is inversely proportional to the luminance level under test. For instance if a display has a half-life of 10,000 hours for the corresponding luminance of 100 nits then it is expected to have a half-life of 1,000 hours if tested under 1000 nits conditions. Furthermore the lifetime is expected to be about 100,000 hours if tested under 10 nits conditions. We expect this relation to hold under different temperatures."

To add this drive relationship to the equations developed so far, the consumption rate formulas are simply modified by multiplying the equations by the factor L_{op}/L_N where L_{op} is the operating

luminance and L_N is the normal operating luminance under which the devices were tested. Since the integral of a constant times a function is the constant times the integral, the luminance decrease formulas can simply be multiplied. Therefore the new equations for luminance decrease (LD) are as follows.

$$LD_{50C} = \frac{L_{OP}}{L_N}\left\{0.0047t + (0.038429)(0.08)\left[1 - e^{-t/0.08}\right]\right\} = \frac{L_{OP}}{L_N}\left\{0.0047t + 0.00307\left[1 - e^{-t/0.08}\right]\right\}$$

(Eq 3.1)

$$LD_{85C} = \frac{L_{OP}}{L_N}\left\{0.0047t + (0.5653)(0.045)\left[1 - e^{-t/0.045}\right]\right\} = \frac{L_{OP}}{L_N}\left\{0.0047t + 0.02544\left[1 - e^{-t/0.045}\right]\right\}$$

(Eq 3.2)

4.0 Automotive Life Example

An estimate of how the OSRAM Yellow OLED material will decrease in luminance in a worst case scenario such as Phoenix, Arizona is determined as follows using Equations 3.1 and 3.2. Assuming 10years at 15Kmi/year (150Kmi total) and an average speed of 30mi/hr, the total number of operational hours is determined per Equation 4.1.

$$HOURS_{OPERATIONAL} = \frac{150Kmiles}{30\, mi/hour} = 5000hours \qquad \text{(Eq 4.1)}$$

Assume ½ time night and ½ time day driving.
Assume ½ summer and ½ winter driving scenario.
Assume 2 hot starts per day during summer (car is soaking in the sun and display is at 85°C (185°F) including sun load).
Therefore assuming 2 hot starts/day during summer days,

$$10years \times 365days \times \frac{1}{2}summer \times 2hot\_starts/day = 3650hot\_starts \qquad \text{(Eq 4.2)}$$

Assuming 85°C hot starts, using Equation 3.2, each hot start will consume 25.44mNit of life.

$$\therefore 3650hot\_starts \times 25.44mNits = 92.8Nits \qquad \text{(Eq 4.3)}$$

Equation 4.3 predicts that the OLED luminance will decrease by 92.8 Nits due to 85°C hot starts. Note that it is assumed that $L_{OP}=L_N$ for day time operation.

The total operating time at 25°C during full 240 Nit daytime luminance is ½ x 5000 hours = 2500 hours. Note that once again $Lop/L_N = 1$ for full luminance day time operation.

$$\therefore 2500hours \times 0.0047\, Nits/hour = 11.75Nits \qquad \text{(Eq 4.4)}$$

Assume 40 Nits for night time operation at 25°C for 2500 hours.

$$\therefore 2500 hours \times 0.0047\ Nits\big/ hour \times \frac{40 Nits}{240 Nits} = 1.95 Nits \qquad \text{(Eq 4.5)}$$

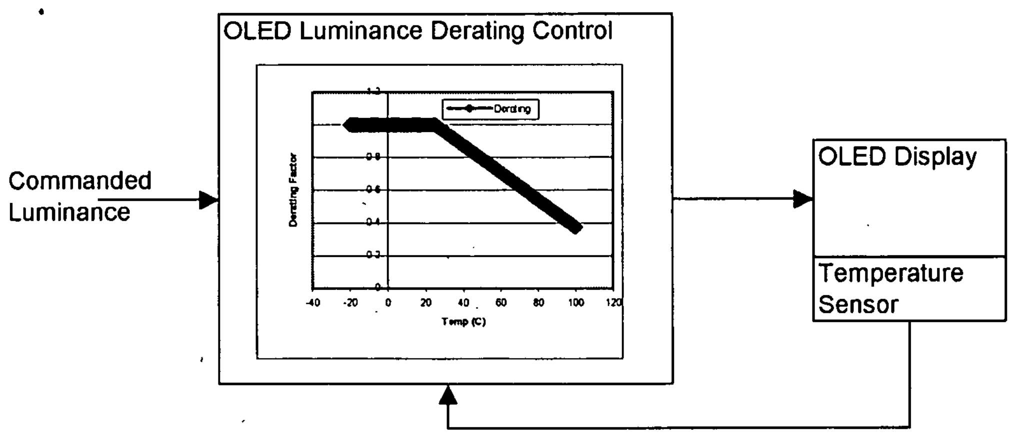
Therefore in summary:

Condition	Luminance Decrease
3650 +85°C Hot Starts	92.8 Nits
2500 hours @ 240 Nit Day Time Operation	11.75 Nits
2500 hours @ 40 Nit Night Time Operation	1.95 Nits
Total Luminance Decrease @ End of Life	106.5 Nits (44% decrease)

One can see from this analysis that most of the damage is caused due to the short time the OLED is operated in a hot condition until the temperature is brought back to a liveable condition either by air conditioning or windows open. This amount of decrease would be extremely annoying on a matrix display, and is marginal at best on a segmented display.

5.0 Temperature Compensation Versus Automatic Luminance Compensation

Although automatic light sensing has been considered to decrease the amount of luminance loss, from the analysis it is clear that the major loss is not due to normal operation, but rather for the few minutes at initial hot temperature start. This is due to the exponential nature of the loss as the temperature increases. Therefore a better strategy may be to decrease the luminance as a function of temperature. As an example of temperature compensation, assume that the display luminance is decreased linearly from full luminance at 25°C to 50% of full luminance at 85°C (note other non linear schemes may be better). Therefore we want to start at normal luminance, L_N, at 298°K and decrease to $0.5xL_N$ at 358°K (85°C).



File:OLED Block Diag

Figure 5.1 Temperature Derating Block Diagram

The simultaneous equations are as given in 5.1 through 5.6 to yield Equation 5.7 which gives the operational luminance as a function of temperature in Kelvin.

$$L_{OP} = mT_K + b \qquad \text{(Eq 5.1)}$$

$$L_N = m298 + b \qquad \text{(Eq 5.2)}$$

$$0.5L_N = m358 + b \qquad \text{(Eq 5.3)}$$

Subtracting Equation 5.3 from Equation 5.2 yields Equation 5.4.

$$0.5L_N = -60m \qquad \text{(Eq 5.4)}$$

$$\therefore m = -\frac{0.5L_N}{60} \qquad \text{(Eq 5.5)}$$

$$b = L_N + \frac{0.5(298)L_N}{60} = 3.48L_N \qquad \text{(Eq 5.6)}$$

$$L_{OP} = -\frac{0.5L_N T_K}{60} + 3.48L_N = L_N\left[-\frac{0.5T_K}{60} + 3.48\right] \qquad \text{(Eq 5.7)}$$

Equation 5.7 linearly decreases L_{OP} from L_N @ 25°C to $0.5xL_N$ @ 85°C.

Equation 5.7 can now be used in conjunction to develop a new consumption rate (CR) formula and then solve for Luminance Degradation (LD).

$$LD = \int_0^t CRdt = \int_0^t \frac{L_{OP}}{L_N} \frac{250(0.1)}{1.968\times 10^{-9}} \frac{1}{e^{8.53K\left(\frac{1}{T_K}\right)}} dt \qquad \text{(Eq 5.8)}$$

Substituting Equation 5.7 into Equation 5.8 yields Equation 5.9.

$$LD = \frac{250(0.1)}{1.968\times 10^{-9}} \int_0^t \frac{L_N\left[\frac{-0.5T_K}{60} + 3.48\right]}{L_N} \frac{1}{e^{8.53K\left(\frac{1}{T_K}\right)}} dt \qquad \text{(Eq 5.9)}$$

$$T_K = 298 + 60e^{-t/0.15} \qquad \text{(Eq 5.A)}$$

Equation 5.A is a 20 minute decrease in temperature from 85C to 25C.

$$LD = \frac{250(0.1)}{1.968\times 10^{-9}} \int_0^t \frac{L_N\left[\frac{-0.5\left(298 + 60e^{-t/0.15}\right)}{60} + 3.48\right]}{L_N} \frac{1}{e^{8.53K\left(\frac{1}{298+60e^{-t/0.15}}\right)}} dt \qquad \text{(Eq 5.B)}$$

However as shown earlier, the last term and the leading constants can be curve fitted to provide Equation 5.C.

$$LD = \int_0^t \left[\frac{-0.5\left(298 + 60e^{-t/0.15}\right)}{60} + 3.48 \right] \left[0.0047 + 0.5653e^{-t/0.045} \right] dt \qquad \text{(Eq 5.C)}$$

$$LD = \int_0^t \left[1 - 0.5e^{-t/0.15} \right] \left[0.0047 + 0.5653e^{-t/0.045} \right] dt \qquad \text{(Eq 5.D)}$$

$$LD = \int_0^t 0.0047 + 0.5653e^{-t/0.045} - 0.5(0.0047)e^{-t/0.15} - 0.5(0.5653)e^{-t/0.15}e^{-t/0.045} dt \qquad \text{(Eq 5.E)}$$

$$LD = 0.0047t\Big|_0^t + \left.\frac{0.5653e^{-t/0.045}}{\left(\frac{-1}{0.045}\right)}\right|_0^t - \left.\frac{0.5(0.0047)e^{-t/0.15}}{\left(\frac{-1}{0.15}\right)}\right|_0^t - 0.5(0.5653)\int_0^t e^{-t\left(\frac{1}{0.15}+\frac{1}{0.045}\right)} dt \qquad \text{(Eq 5.F)}$$

$$LD = 0.0047t - 0.0254e^{-t/0.045}\Big|_0^t + 0.0003525e^{-t/0.15}\Big|_0^t - 0.5(0.5653)\int_0^t e^{-t/0.0346} dt \qquad \text{(Eq 5.G)}$$

$$LD = 0.0047t + 0.0254\left[1 - e^{-t/0.045}\right] - 0.0003525\left[1 - e^{-t/0.15}\right] - \left.\frac{0.28265e^{-t/0.0346}}{\left(\frac{-1}{0.0346}\right)}\right|_0^t \qquad \text{(Eq 5.H)}$$

$$LD = 0.0047t + 0.0254\left[1 - e^{-t/0.045}\right] - 0.0003525\left[1 - e^{-t/0.15}\right] - 0.0098\left[1 - e^{-t/0.0346}\right] \qquad \text{(Eq 5.I)}$$

From Equation 6.8, one can see that the 1st two terms are the luminance degradation calculated earlier. From lowering the luminance to ½ @ 85C, the last two terms show how much luminance degradation can be saved. Therefore assuming 3650 hot starts, the luminance saving is calculated per Equation 5.J.

$$LD_{Saving} = 3650 \times (0.0003525 + 0.0098) = 55.66 Nits \qquad \text{(Eq 5.J)}$$

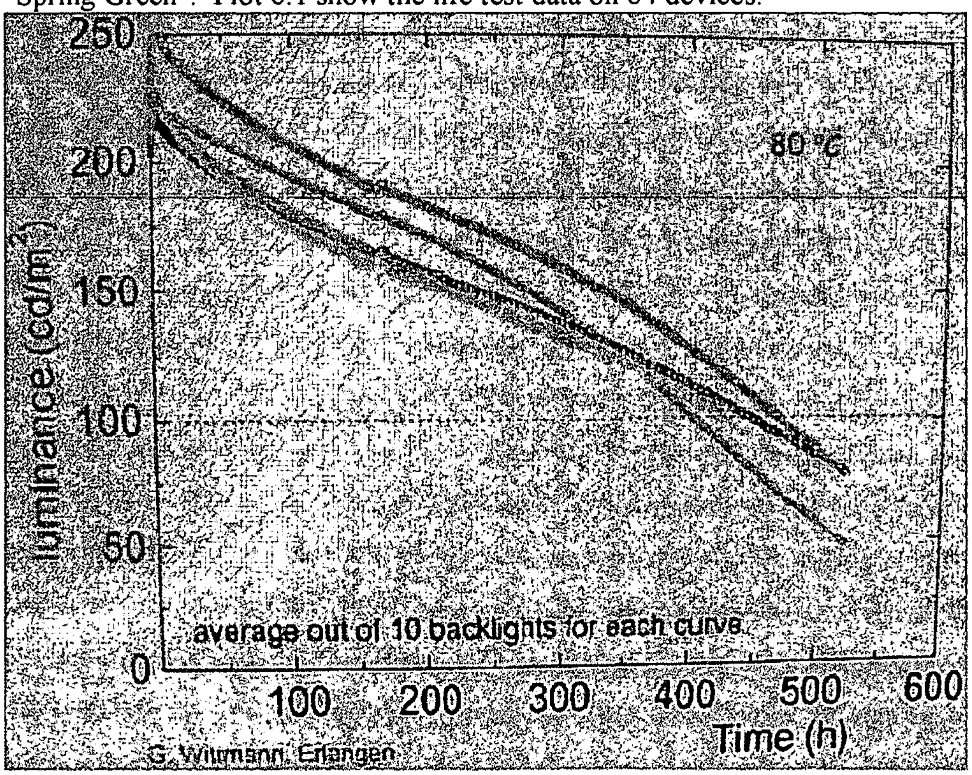
Condition	Luminance Decrease	Luminance Decrease with Temperature Derating
3650 +85°C Hot Starts	92.8 Nits	37.14 Nits
2500 hours @ 240 Nit Day Time Operation	11.75 Nits	11.75 Nits
2500 hours @ 40 Nit Night Time Operation	1.95 Nits	1.95 Nits
Total Luminance Decrease @ End of Life	106.5 Nits (44% decrease)	50.84 Nits (20% decrease)

Table 5.1

Table 5.1 shows that the luminance degradation has now been reduced to 20% which may make it acceptable for a segmented display. What is also important to remember is that the reduction for a segmented display will be better because the duty cycle is decreased.

6.0 New OSRAM Spring Green Material

OSRAM is developing a higher glass transition temperature fluorine based material called "Spring Green". Plot 6.1 show the life test data on 64 devices.



The average life time is 400hours at 80C from a starting point of about 225 Nits. At 25C, the lifetime is longer than 20,000 hours. From this data, the luminance degradation can be recalculated, but a quick metric is to look at the decay rate.

$$\frac{Nits}{Hour} = \frac{225-100}{450} = 0.277 Nits/Hour \quad \text{(Spring Green)} \qquad \text{(Eq 6.1)}$$

This can be compared to the OSRAM yellow at about

$$\frac{Nits}{Hour} = \frac{280-160}{200} = 0.6 Nits/Hour \quad \text{(Yellow)} \qquad \text{(Eq 6.2)}$$

Therefore one would expect that the green material would decay less than ½ as much as the yellow material over the automotive life and would put it in the realm of useable for segmented displays. However, until the 20,000K+ hour number is known, the exact calculations cannot be done.

7.0 Conclusions

- This analysis shows that metrics should be obtained from each OLED vendor. These metrics consist of life testing data at two temperatures. From this data, the luminance degradation can be normalized for comparison between vendors and materials and can be used to estimated luminance degradation over the automotive life.
- If temperature derating methods are utilized, the use of OLEDs becomes more plausible for segmented displays. The temperature derating method lowers the display luminance during the short periods of time during initial hot start up. Differential aging is not as noticeable in segmented displays due to the black separation area between segments. More study is required in this area to determine the limit of acceptable differential aging for segmented displays.
- The use of matrix displays for continuous use applications is not recommended at this time due to the differential aging problem especially at high temperatures.